JUNE 30, 1986

CHEMICAL & ENGINEERING

NEWS

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Chemists get slightly bigger slice

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CHEMICAL & ENGINEERING
NEWS

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Salary Survey

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New Era of Inherently Safe Nuclear Reactor Technology Nears

Chernobyl accident overshadows culmination of development work aimed at improving reactor safety and reliability

Joseph Haggin, C&EN Chicago

It is still too early to assess the ultimate impacts of the Soviet nuclear reactor failure at Chernobyl at the end of April. But one positive result has appeared. A renewed focus on nuclear reactor safety has highlighted more than a decade of largely unheralded work by U.S. and western nuclear engineers aimed at improving reactor safety and reliability.

That work intensified following the reactor incident in 1979 at Three Mile Island, near Harrisburg, Pa. Almost unnoticed, the U.S. since then has edged into a new era in reactor technology built around liquid-metal reactors (LMR), more-reliable pressurized-water reactors (PWR), improved fuels, and more-secure reprocessing and waste disposal.

For the nuclear community, the biggest disappointment during the period has been the demise of the Clinch River breeder project. The U.S. government's decision to halt funding on that project effectively handed the world's lead in breeder reactor technology to the French. If the U.S. now decides to get back into the breeder business, it may find itself in the position of having to buy its technology from French sources. That prospect goes down hard among the nuclear fraternity, but it may someday become necessary if the U.S. is to generate nuclear power economically.

About a dozen types of commercial nuclear power reactors are now operating in the world. The dominant type, a virtual standard, is the pressurized light-water-moderated and -cooled reactor, or PWR. More than half the world's known reactors are of that type. In the U.S., 62 of the 100 operational reactors are PWRs.

The principal builder of PWRs in the U.S. is Westinghouse, which has been in the business for more than 30 years. The changes that have taken place, particularly those concerning reactor safety, have not been revolutionary. Raymond George, Westinghouse's manager of plant marketing, says the technical changes made from time to time have been neither great nor frequent. PWR technology is now mature, and progress is measured in small, regular increments. However, Westinghouse has cooperative agreements with Japanese nuclear interests to develop advanced PWRs.

A strong influence on the technology has been the advanced pressurized water reactor (APWR) project, in which George formerly was engineering manager. The APWR program employed extensive simulation and "what if" incidents to simulate nuclear power-downs of every possible kind. A major result was a decision to separate control and safety functions in nuclear power operations.

The important distinction is that separating safety and control systems provides yet another level of redundancy above that prescribed by the Nuclear Regulatory Commission. Control systems involve the actual operating control of the reactor on a routine basis. Safety systems operate when abnormal conditions are encountered. The two systems are interconnected but separate.

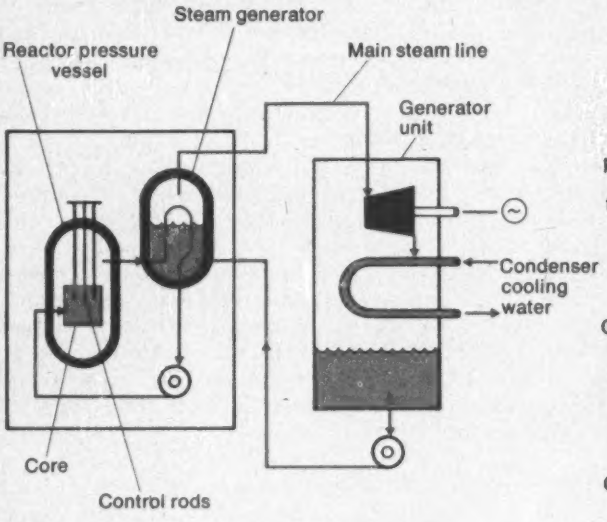
George believes that present PWRs are inherently safe, and the probability of a reactor shutdown caused by the most likely incidents is less than one in a million reactor years. It is possible to decrease the probability of shutdown by two more orders of magnitude, but many doubt that that would be of any actual benefit. George notes that the probability of shutdown has been decreased to roughly the level of a major meteoric impact on Earth's surface.

George believes that two principal incentives need to be considered concerning reactor safety. First is the obvious concern with public safety during a power shutdown. That is what most people fear when they address reactor safety. The only U.S. experience has been the Three Mile Island incident. TMI resulted in no hazard to the public because, George points out, the containment measures functioned as they were designed to function.

Much partisan publicity, pro and con, has been generated about TMI, but the reality is that no damage to the population resulted. The Chernobyl accident was, apparently, quite different. Although the causes and effects of the Chernobyl incident are still largely unknown, an obvious breach of integrity in reactor containment occurred. In fact, there apparently was no containment around the reactor.

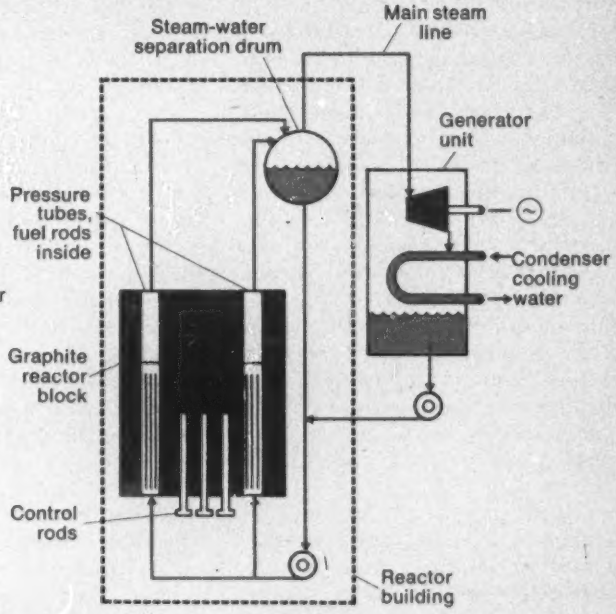
The second safety incentive, after concern for the public, is economic protection for the reactor owners. George suggests that people frequently fail to realize that the great investment in a nuclear power reactor is possibly one of the biggest single reasons for minimizing the effects of power-down. The owners have multibillion-dollar investments and can afford neither lengthy shut-

Typical U.S. pressurized-water reactor has containment...



Pressurized-water reactor uses fuel of slightly enriched uranium pellets encased in Zr-alloy fuel rods. Water is pumped through the core to remove fission heat. This water is pressurized to keep it liquid. Heat is transferred to intermediate steam generation system, which supplies steam to the generator. All units with a radioactive potential have protective containment structures

... graphite-moderated reactor at Chernobyl did not



RBMK-1000 reactor uses pellets of slightly enriched UO_2 sealed in Zr-alloy fuel rods. Bundles of rods are inserted directly into pressure tubes placed in the graphite moderator block. Water rising through the tubes is converted to steam by fission heat. Steam drives the turbine and is recycled. No containment structures were in use

Source: Atomic Industrial Forum

downs nor permanent closing before the productive lifetime of a unit has run out.

So considering the 35 years or so of relatively safe operation, PWR is the technology to beat in the present nuclear market. George is optimistic about the future of PWRs because they have a fine safety record, have proved to be effective, and will make it difficult for new types of reactors to compete. Most of the present concern about reactor safety, George believes, is misdirected. The record, he says, speaks for itself.

The decade following TMI happened to be the decade of consolidation for the computer. And it was inevitable that the computer would be employed to improve reactor safety.

Every utility company operating nuclear reactors has extensive computerization networks for control, warning, safety, and inventory control. Numerous research organizations and state governments duplicate those networks. Many believe that additional computer control will somehow raise reactor safety to new heights and that greater redundancy provided by additional computer systems is desirable in any event. It's debatable whether greater redundancy is needed, however.

One of the more extensive computerized monitoring systems is being developed at the University of Illinois in a program directed by Magdi Ragheb. He notes that the main causes of nuclear incidents are human error and equipment failure. Human operators can't hope to accommodate the data avalanche that ensues from even a slight upset in a nuclear plant. The answer, Ragheb suggests, is use of a supercomputer to process data, simulate the problem faster than it is actually happening, and forecast the result. That, in principle, would permit operator intervention, or automatic shutdown if necessary. The general idea has been applied in chemical process control for some time by a number of control laboratories, such as that at Purdue University under the direction of Theodore J. Williams.

If Ragheb's system is eventually developed, one of the first places it might be employed is in the State of Illinois Radiological Emergency Assessment Center. Illinois already has nine nuclear reactors in operation and four more under construction. Government monitoring of the reactors is being carried out by the center, and it would be easier, and probably more effective, if a system such as Ragheb's were used.

Meanwhile, some significant developments have emerged in reactor safety. They concern the design of new reactor types that are inherently safe; that employ new types of fuel that are easier and safer to make, use, and dispose of; and that are probably cheaper to build and operate. As a somewhat ironic coincidence, two major tests of those developments were completed suc-

cessfully just before the accident at Chernobyl. Had that accident not occurred, the tests might well have gone unnoticed.

The development of liquid-metal reactors (LMRs) is being carried out under the auspices of the Department of Energy. That development is about all that survives from the Clinch River breeder project, and it contains the remnants of breeder development in the U.S. The main thrust of the project involves the integral fast reactor (IFR) idea. According to Charles E. Till, associate laboratory director for engineering research at Argonne National Laboratory, the main IFR features include liquid-sodium cooling, a pool reactor configuration, new metallic fuel, and an integral fuel cycle.

A basic idea of the design, Till explains, is to exploit the properties of liquid sodium as a coolant for the nuclear reactor. With sodium cooling, it is possible to operate the primary cooling system at atmospheric pressure. The boiling point of sodium is about 1600 °F. In a sodium-cooled reactor, coolant inlet temperatures are typically 650 °F and exit temperatures about 950 °F. That provides about a 500 °F temperature cushion and keeps temperature ranges within the limits of conventional containment materials.

Incorporating a coolant pool into the design configuration provides the safety inherent in a large thermal inertia, in that the pool can absorb reactor heat for a prolonged period. Even with total loss of coolant pumps, the natural convection in the pool is sufficient to transfer reactor heat to the coolant without damaging the core.

Nuclear designers have been trying to develop new metallic fuels for a long time. High thermal conductivity in the fuel itself permits low-temperature operation, while permitting the reactor to remain stable when power is reduced. That's another inherently safe condition.

Also, with metallic fuel, metallurgical fabrication procedures are simpler. According to Till, superior neutronics result, including the potential for excellent breeder capabilities. Generic metal fuels can now be designed with excellent radiation performance. For instance, a new fuel developed at Argonne's experimental breeder reactor-II (EBR-II) in Idaho has burnups exceeding 140,000 MW-days per ton of fuel.

The IFR, as envisioned at Argonne, also would include its own fuel fabrication and reprocessing facility. If that fuel cycle were used in a future commercial facility, the only time radioactive materials would need to enter or leave a reactor site would be when the reactor is built and when it is decommissioned. It is assumed that high enough breeder capacity would be used to eliminate the need for refueling from exterior sources. That would considerably improve operating safety by eliminating much of the over-the-road transportation otherwise needed for fuel and waste materials.

Till sees at least nine advantages of the IFR:

- Fuel performance is excellent. The metal fuels have burnup rates at least as high as those of conventional oxide fuels, and they have an appreciable neutronic advantage over the oxides.
- The metallic fuels are easy to make.
- Reprocessing techniques are simpler and cheaper than the conventional Purex process used for oxide fuels.
- Inherently greater safety results from using metallic fuels.
- IFR economics are expected to be in the LWR range and significantly better than for other LMR choices.
- The amount of radioactive waste is very small and easily managed.
- The need to transport plutonium-bearing fuel is eliminated.
- Because the fuel is made onsite, the chance for theft is greatly reduced.
- The system is well suited for designs above the 1000-MW(e) range. Or, because of its modular character, the IFR also can be adapted to small-unit power stations. Thus, plants can be dispersed—another intrinsically safe procedure.

In cooperation with General Electric and Rockwell International, two of the partners in DOE's LMR program, Till's group has estimated some of the economics of IFRs. The base design for estimating is a conceptual IFR that provides a generating capacity of 1200 to 1400 MW(e).

Preliminary cost estimates suggest that the initial capital investment would be about $57 million, or average fixed charges of about 0.5 mill per kWh. Operating and maintenance costs are about 1.2 mills per kWh, and assembly hardware costs are 1.3 mills per kWh. The fuel cycle can be started up with either plutonium or uranium-235. Although ^{235}U is more desirable, it is also more expensive.

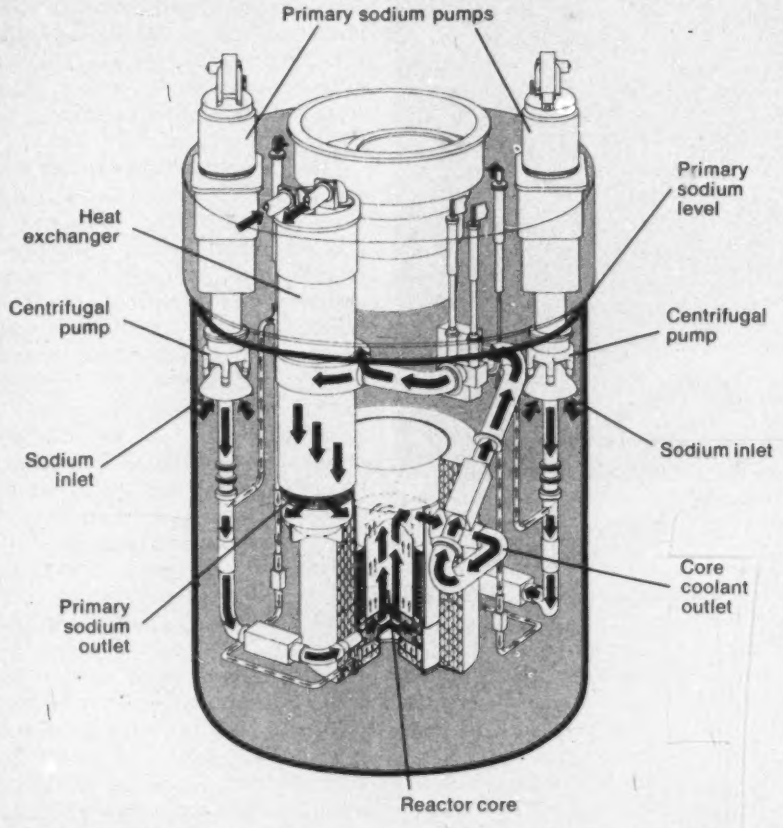
One of the commercial developers in the IFR program is Atomics International, a unit of Rockwell International's Rocketdyne division. John McDonald, director of Atomics International, says that AI's version of the LMR is called the sodium advanced fast reactor (SAFR). It typifies the thrust toward more advanced innovative designs to create a less expensive, viable alternative to LWRs and to serve as a bridge to breeders that are expected to be needed in the future. It is, in effect,

Most of world's reactors are pressurized-water type

Reactor type	Operational	Building	Planned
Advanced gas-cooled, graphite-moderated	10	4	—
Boiling light-water-cooled and -moderated	79	15	3
Fast breeder	6	3	3
Gas-cooled, graphite-moderated	33	—	—
High-temperature, gas-cooled, graphite-moderated	3	—	—
Heavy-water-moderated, boiling light-water-cooled	1	1	—
Light-water-cooled, graphite-moderated	28	7	8
Pressurized heavy-water-moderated and -cooled	24	14	9
Pressurized light-water-moderated and -cooled	189	113	77
Steam-generating, heavy-water	1	—	—
Other types (unspecified)	—	—	16
TOTAL	374	157	116

Note: Types of nuclear power reactors as of Jan. 1, 1986
Source: International Atomic Energy Agency

Integral fast reactor has liquid sodium pool



A deep pool of thousands of gallons of liquid sodium accounts for much of the safety inherent in Argonne National Laboratory's integral fast reactor concept. The reactor core is submerged in the pool. Even without pumps to circulate sodium coolant, natural convection currents in the pool can keep the core from overheating

a "second generation" of nuclear reactor technology.

The SAFR plant employs a 350-MW(e) pool-type, liquid-metal (sodium) Power Pak as the basic module. The Power Pak is a standard, shop-fabricated unit that can be shipped to a plant site by barge. Modules can be used individually or in multiples to accommodate varying power demands. The 350-MW module was considered to be an optimum size by a number of utility companies and was also selected because it was about the largest unit that could be shipped by barge. It is also the largest module that could be built with a completely passive, reactor air cooling system for the removal of decay heat.

All the primary coolant in a SAFR is contained within the stainless steel reactor vessel, 39 feet in diameter and 48 feet high. A guard vessel around the reactor maintains a safe sodium level above the core. There are no penetrations in either the guard vessel or the reactor itself. All piping and instrument channels enter and exit through the top. Heat transfer is accomplished by new pump and piping designs.

The core of SAFR, McDonald says, can use either conventional mixed oxide (uranium/plutonium oxides) or the new metal fuels. Extensive experience has been gained with the oxide fuels, but the new fuels offer the advantages cited by Argonne's Till.

The fuel cycle for SAFR is envisioned at about four years, with 25% of the fuel being replaced each year. Although SAFR is not now designed for breeder operation, the reactor will accept breeder cores in the future. Spent fuel is allowed to decay for a year before being transferred to storage. If on-site fuel reprocessing is desired, it can be accommodated with little trouble. In addition to the reactor itself, containment consists of the guard vessel and an all-enclosing steel-lined concrete box.

As in the PWRs cited by Raymond George, reactor control systems have been decoupled from the safety systems. That design provides additional redundancy in safety systems and simplifies the construction of intermediate heat transfer systems. Public safety and investment protection are ensured by a variety of active and passive systems. The ultimate safety device is the design itself, which allows the reactor to be shut down to a totally passive condition without damage or hazard.

McDonald says that commercialization of the LMRs depends on completing final tests of reliability, financing, licensing, and the like. One plan proposes that a single module plant be built and operated by the late 1990s as a basis for obtaining a codified standard design approval from NRC.

The second commercial developer, General Electric, has designed a 135-MW(e) power reactor inherently safe module (PRISM) intended for factory assembly and transportation to an operating site by rail. PRISM is also a pool-type reactor that uses liquid sodium. The reactor will breed enough fuel to feed itself. The nuclear envelope is self-contained, and parts are designed for fabrication and assembly in a factory. The GE design calls for placing each reactor in an underground silo, with the steam generator in an adjacent silo. The rest of the plant is of conventional design.

A commercial PRISM plant would consist of three segments, each containing three PRISM modules. Each segment would be functionally independent but would be connected to a common steam drum. Heat from the reactor is transferred to a primary sodium loop and then to a secondary system before being used to produce steam.

The PRISM containment vessel is 19 feet in diameter and 64 feet high. It weighs 950 tons without fuel. The design accommodates Argonne's new fuel as well as conventional

Argonne National Laboratory engineers watch as coolant pumps are shut down during a test of the inherent safety of sodium-cooled nuclear reactors

oxide fuels. In addition to the primary containment of the reactor itself, the design includes a secondary containment system and an outer concrete barrier.

General Electric estimates that fabricating the first modules would take about three years, once the factory is built. Thereafter, a module might be built every three and a half months. Construction on-site would require another three years. Assuming the best design-fabrication-construction scenario, it might be possible to complete a 1200-MW(e) power station in 49 months by installing modules as they are made and bringing the plant on stream module by module. If the nuclear power business expands as is hoped, it would be possible to have modules "on the shelf" ready to meet orders.

The ultimate test of an inherently safe design is to "pull the plug" and walk away from an operating unit. In effect, that's what Argonne did early in 1986. Between February and early April, a series of tests were conducted with EBR-II operating as an IFR. The tests left little doubt that an inherently safe design had, in fact, been developed.

According to Charles Till, on April 3, two potentially serious accident situations were initiated within hours of each other with the reactor operating at full power. In both cases, the plant shut itself down without any action by operators or the normal plant safety systems. Till maintains that no other type of reactor design could have survived accidents of that severity.

The first "accident" was a direct simulation of the classical loss of flow without scram—the emergency dropping of all control rods to instantaneously shut down the core. That is the ultimate control technique and effectively stops the core from functioning. Loss of flow without scram means that the rods were not dropped, and the core continued to function. With the plant operating at full power, protection systems were rendered inoperative, and power to the primary, secondary, and auxiliary pumps was instantaneously shut off. In effect, an instantaneous power blackout was created.

The reactor continued to run without forced cooling. Core temperatures rose, generating negative reactivity, which reduced the power level to zero. Although the coolant temperature rose briefly, it soon stabilized at a normal value. Till says the reactor would have remained in that condition indefinitely, if the test had not been terminated.

In a few hours, the second "accident" followed. It involved a total loss of heat sink without scram and with the reactor at full power. In many respects, that was similar to the accident at Three Mile Island. Again the results were about the same. The reactor simply shut itself off.

Those tests followed similar tests a few months earlier with the same results. Till emphasizes that EBR-II is a small reactor—20 MW(e). However, as noted by McDonald and others, it also approaches the size of the envisioned LMR modules, and it provides an active simulation of several of the most serious accidents that can be encountered on site. Simultaneous computer simulation verified the results of the EBR-II tests.

Following the Chernobyl accident, one of the most frequent charges by antinuclear advocates has been that all reactors pose inherent danger. They are radioactive, say the advocates, and therefore dangerous. The conflicting reports about nuclear safety written in the early 1970s are repeatedly brought up for reappraisal. It seems to have escaped notice that a lot has happened since the early 1970s and, in particular, since Three Mile Island. Safety, already high at the time of the Three Mile Island incident, has been greatly improved in the interim. Now a new generation of power reactors is about ready for commercial demonstration. Even an ardent foe of nuclear power should find the dramatic tests of EBR-II rather convincing. □

U.S. has mostly pressurized-water reactors

U.S. reactor types	Number
Westinghouse Electric	
Pressurized-water reactors	40
General Electric	
Boiling-water reactors	35
Graphite reactor	1
Combustion Engineering	
Pressurized-water reactors	14
Babcock & Wilcox	
Pressurized-water reactors	8
General Atomic	
High-temperature gas-cooled reactor	1
Allis Chalmers	
Boiling-water reactor	1
TOTAL	**100**

Note: As of April 1, 1988, there were 100 operable reactors in the U.S., including 93 in commercial production, three with full-power licenses but not yet in full production, and four with low-power operating licenses. An additional 28 reactors have construction permits and two more are on order. Source: Atomic Industrial Forum

Unemployment Slightly Higher For Chemists in the Past Year

Salaries rise more than does the cost of living, with Ph.D. chemists faring best this year, ACS survey indicates

The U.S. chemical industry has taken unprecedented steps to streamline its operations and enhance its efficiency during the past year or so. Throughout the industry, companies large and small have shut down or sold off unproductive plants, dropped profitless or unpromising lines of business, pared their work staffs, and made other moves to prune operating costs. One result: Employment in the industry fell more than 20,000 (about 2%) between the end of 1984 and the end of last year, and has continued to decline since then.

This dramatic wave of corporate restructuring appears to have had relatively limited effect on the overall economic well-being of U.S. chemists, however. Unemployment has edged up a bit for chemists, to be sure, although it is no higher this year than it was a couple of years ago. Meanwhile, salaries earned by chemists, particularly those with a Ph.D. degree, have scored one of the best gains of recent years. In fact, after adjustment for inflation—which lately has been at its weakest since the early 1970s—salaries have made an especially strong showing during the past year.

As of last March, the unemployment rate for chemists who are members of the American Chemical Society was 1.7%, the latest ACS survey of the economic status of its members indicates. That is up from 1.4% a year earlier to the same level as in March 1984. As has been true in the past, unemployment among chemists is far lower than for the U.S. labor force as a whole—the overall rate of unemployment in the U.S. was 7.1% last March—and also is slightly less than unemployment among all professional workers, for whom the rate was 2.0% in March.

The small increase in unemployment this year is centered largely on industrial chemists. The joblessness rate for chemists whose current or most recent job is in private industry climbed to 2.2% this year, up from 1.5% in 1985 and 1.8% in 1984. And unemployment seems especially high for chemists working in production or marketing jobs. On the other hand, joblessness is lower this year for academic and government chemists than it was in 1985.

Unemployment, though generally low, is highest for chemists without a graduate degree

	Chemists									
		By sex		By highest degree			By minority status			
Employment status[a]	Total	Men	Women	B.S.	M.S.	Ph.D.	Minority[b]	Nonminority	Chemical engineers	All members[c]
Employed full time	93.7%	94.7%	88.7%	94.1%	94.7%	93.3%	91.2%	94.0%	93.5%	93.5%
Employed part time	1.6	0.9	4.7	1.4	2.1	1.4	1.8	1.6	1.8	1.6
Postdoctoral or fellowship	1.8	1.8	1.9	0.0	0.1	3.2	4.3	1.6	0.4	1.7
Unemployed										
Seeking employment	1.7	1.6	2.0	2.6	1.7	1.3	2.2	1.6	2.4	1.8
Not seeking employment	1.2	0.9	2.6	1.9	1.4	0.8	0.5	1.2	1.8	1.4

a As of March 1, 1986. b Black, Hispanic, American Indian, Alaskan native, Asian, Pacific Islander, or other. c Includes ACS members whose highest degree and present work are in neither chemistry nor chemical engineering. **Source:** ACS survey

Chemists with Ph.D.s win biggest salary increases in the past year

												Annual change		
$ Thousands	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976	1985–86	1981–86	1976–86
CHEMISTS' MEDIAN SALARIES[a]														
B.S.	$33.0	$32.0	$30.9	$30.0	$28.5	$27.5	$25.0	$23.5	$22.0	$21.0	$19.8	3%	4%	5%
M.S.	37.9	36.0	34.0	33.0	31.6	30.0	26.0	25.0	24.0	22.0	20.5	5	5	6
Ph.D.	47.8	44.0	42.0	40.0	37.5	35.0	31.2	29.0	27.4	26.0	24.7	9	6	7
All chemists	42.5	40.0	38.0	36.0	34.7	32.0	28.9	na	na	na	na	6	6	na

a As of March 1, 1986. na = not available. **Source:** ACS survey

Salaries tend to increase most rapidly during the first 20 to 30 years of a chemist's career

Years since B.S. degree	Median salary ($ thousands)[a]										
	0 to 1	2 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 or more	Overall
NONACADEMIC CHEMISTS											
B.S.											
90%	$27.5	$30.0	$38.0	$47.0	$52.0	$55.2	$60.9	$64.8	$64.0	$73.0	$52.5
75%	24.0	27.0	33.5	40.0	45.0	50.0	50.2	54.0	55.0	57.0	43.0
50%	21.0	24.0	29.0	34.5	39.0	43.0	43.0	45.0	47.0	42.9	33.8
25%	18.8	20.6	25.0	28.0	32.0	36.0	35.2	36.2	39.0	34.0	26.0
10%	15.0	17.6	21.0	24.6	28.0	27.9	29.0	31.0	29.1	25.0	21.8
M.S.											
90%	—	32.2	40.0	47.0	55.0	61.0	64.7	67.8	68.8	82.5	60.0
75%	—	30.0	34.7	42.0	48.0	52.7	55.0	59.8	59.0	60.2	48.8
50%	—	27.0	30.5	35.8	40.0	42.0	46.3	50.0	50.0	49.5	39.0
25%	—	23.8	26.8	30.6	34.0	35.0	37.0	40.0	43.9	42.5	31.7
10%	—	22.0	24.0	26.9	30.0	29.6	27.2	32.6	34.0	29.5	26.8
Ph.D.											
90%	—	—	45.1	54.0	64.0	75.0	76.0	82.2	85.0	82.4	73.0
75%	—	—	42.0	48.9	55.7	62.6	65.0	69.6	73.3	71.8	60.0
50%	—	—	39.1	43.4	48.0	54.0	55.0	56.4	62.7	60.0	49.9
25%	—	—	36.9	39.6	42.3	45.6	47.1	48.0	52.0	51.0	42.0
10%	—	—	34.0	35.5	37.4	40.0	40.2	41.1	43.8	38.8	37.0

a As of March 1, 1986. **How to read this table:** Using, as an example, nonacademic B.S. chemists two to four years after having received their B.S. degree, 90% of these chemists have annual salaries of $30,000 or less, 75% have annual salaries of $27,000 or less, 50% have annual salaries of $24,000 or less, 25% have annual salaries of $20,600 or less, and 10% have annual salaries of $17,600 or less, as of March 1, 1986. **Source:** ACS survey

It is men, too, and largely those with no more than a bachelor's degree, who have borne this year's increase. The unemployment rate among women chemists, which typically is greater than that for men, is down to 2.0% from 2.4% in 1985. The rate for men, meanwhile, climbed to 1.6% this year from 1.2%. In recent past years, the rate for women chemists has run from 60 to 100% higher than that for men. This year, though, it is only 25% higher.

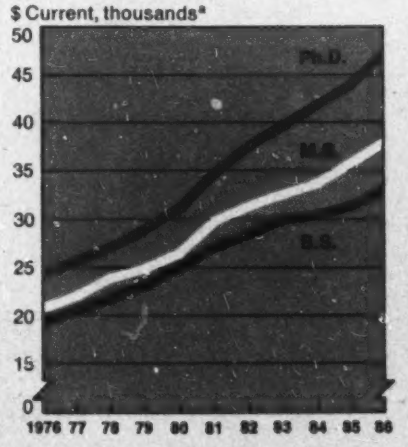
And although unemployment is up only very slightly this year for chemists with a graduate degree, for those with just a B.S. the rate has jumped to 2.6% from 2.0% in 1985.

In one other way the pattern of unemployment is unusual this year. Generally in the recent past, unemployment has varied little with age; if anything, it has tended to be slightly higher for younger chemists, who presumably are more mobile. This year, however, the rate for chemists under 55 is 1.5%; that for chemists between the ages of 55 and 65 is 2.7%. This is consistent with information collected by the ACS Committee on Professional Relations, which indicates that recent large-scale terminations of industrial chemists have most affected older individuals (C&EN, June 23, page 72).

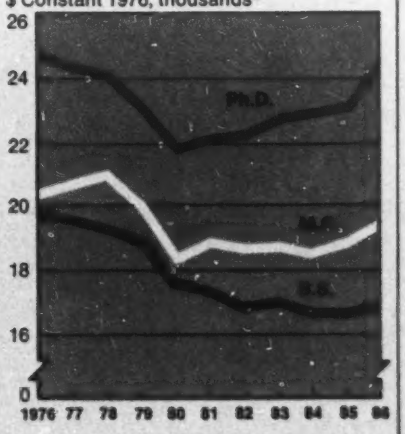
Results regarding salaries from the annual ACS survey, conducted by the ACS Office of Statistical Services earlier this year, present a brighter picture, especially for chemists with a Ph.D. The median annual salary for Ph.D. chemists increased 9% between March 1985 and March 1986, the biggest year-to-year improvement since 1981 and well above the average annual rate of increase during the past decade. (The median is the salary that is exceeded by 50% of the respondents to the ACS survey.) The increase of 3% this year for B.S. chemists and 5% for those with an M.S. degree is more in line with increases in salaries reported by such chemists for previous years. For several years now, salaries of B.S. chemists have been rising at a slower rate than for chemists with graduate degrees, and this year is no exception.

Year-to-year salary increases also

Graduate chemists' salaries have risen enough . . .



. . . to more than offset inflation in past few years



a Median salary of chemists as of March 1 of each year. **Source:** ACS survey

For academic chemists, teaching at a Ph.D.-granting institution earns a higher salary

Years since B.S. degree	Median salary ($ thousands)[a]								
	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 or more	Overall
Ph.D. CHEMISTS EMPLOYED FULL TIME IN ACADEMIA									
Ph.D.-granting schools									
Professor	—	—	$53.0	$54.0	$53.8	$58.4	$62.2	$64.2	$57.4
Associate professor	—	$37.9	40.3	40.3	(42.2)	(39.6)	(49.5)	—	40.3
Assistant professor	$32.8	31.4	(33.5)	—	—	—	—	—	32.4
All ranks[b]	31.3	33.0	39.1	48.4	51.2	55.4	59.9	63.0	47.7
Non-Ph.D.-granting schools									
Professor	—	—	(38.7)	44.5	42.8	46.0	47.7	(51.3)	44.5
Associate professor	—	(31.6)	33.0	36.5	36.4	(42.4)	—	—	35.7
Assistant professor	26.9	27.5	28.7	(33.0)	—	—	—	—	28.1
All ranks[b]	26.9	27.6	32.7	39.1	40.9	45.2	47.1	44.0	39.1

a As of March 1, 1986. b Includes instructors, lecturers, research associates, and others not listed separately. Note: Where no salary data are shown, sample is too small to provide a meaningful figure; data in parentheses are from relatively small samples, as well, and should be viewed with caution. Source: ACS survey

look favorable when compared with the rise in the cost of living. Because inflation has cooled off so much in recent months, the median annual salary for Ph.D. chemists in constant-dollar terms is 6% higher this year than in 1985. That's the best real annual salary increase for Ph.D.s in many years. It certainly is the largest increase since 1981, when the median salary for Ph.D.s began to rise faster than consumer prices following a long period during the late 1970s when salary increases fell behind the rate of inflation. In real terms, therefore, the median for Ph.D.s now is at about the same level as 10 years ago.

For M.S. chemists, this year's increase in median salary, adjusted for inflation, is 3%, the largest gain since 1981. For B.S. chemists, on the other hand, the increase this year is a mere 1%. Because the median salary for B.S. chemists has risen relatively slowly in the past few years, its level, compared with the cost of living, is much less favorable than that for chemists with a graduate degree. As a result, the median for B.S. chemists, in constant dollars, is 14% lower this year than it was 10 years ago.

As in the past, salaries earned by women chemists generally are below those earned by men. In part, this is because age and experience are important factors influencing salary levels, and women chemists as a group are younger and less experienced than men chemists as a group. Thus, nearly 60% of women chemists, but only 30% of men chemists, earned their baccalaureate degree less than 15 years ago.

Even so, when salaries are adjusted to make allowance for differences in length of experience, men maintain a distinct advantage—ranging from about 10 to 20%, depending on highest degree and type of employer. (In adjusting salaries for differences in experience, comparisons must be made between mean rather than median salaries.) The persistent gap between men's and women's salaries does not seem to have changed appreciably in the past few years, moreover. In 1982, for instance, the adjusted mean salary for women chemists with a Ph.D. and working in industry was 96% that for their male colleagues; this year and last, the mean salary for similar women was 89% that for the men. Similarly, for women with a B.S. and working in industry, the adjusted mean salary was 88% that for men in 1982 and 85% that for men this year.

The spread between men's and women's salaries generally is narrow, nevertheless, for chemists who have entered the profession in the past 10 years or so. In fact, this year the median salary of women with a B.S. and working in industry who received their degree less than five years ago actually is higher than that for similar men. But in the upper experience brackets, men hold a strong advantage. The median salary for men in industry with a B.S. obtained 15 to 19 years ago, for example, is about 30% higher than that for women of similar character.

The influence of length of work

Women's salaries overall trail those for men more than 10%

Mean salary, $ thousands[a]	B.S.				M.S.				Ph.D.			
	All chemists	Men	Women	Women as % of men	All chemists	Men	Women	Women as % of men	All chemists	Men	Women	Women as % of men
EMPLOYER												
Private industry	$36.6	$38.6	$32.9	85%	$42.1	$43.9	$36.7	84%	$53.0	$53.8	$47.8	89%
Academic	—	—	—	—	31.8	33.4	29.5	88	44.7	45.6	39.7	87
Government	33.6	35.2	29.6	84	37.4	38.0	34.6	91	48.0	49.1	40.5	82
Other	31.5	32.9	28.5	87	34.0	36.2	31.7	88	50.8	52.9	44.0	83

a As of March 1, 1986; to facilitate comparison, salaries are adjusted for differences in the average experience for each group. Source: ACS survey

For industrial chemists, a job in management brings top pay

Years since B.S. degree		Median salary ($ thousands)[a]										
		0 to 1	2 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	35 to 39	40 or more	Overall
CHEMISTS EMPLOYED FULL TIME IN INDUSTRY												
Sex												
Men	B.S.	$22.0	$24.0	$30.0	$36.0	$40.9	$44.0	$45.0	$46.0	$48.2	$44.8	$37.0
	M.S.	—	(27.1)	32.0	36.6	41.0	45.0	49.7	50.0	51.5	52.5	42.0
	Ph.D.	—	—	39.6	44.0	49.6	57.0	58.5	60.0	64.0	64.0	50.6
Women	B.S.	23.2	25.0	28.0	31.2	31.1	(43.0)	(29.0)	(36.2)	(36.0)	(32.5)	27.5
	M.S.	—	(27.6)	30.0	34.2	40.0	38.0	(37.8)	(33.0)	—	—	33.5
	Ph.D.	—	—	39.3	43.6	46.1	46.0	(49.2)	(49.9)	—	—	42.3
Work function												
General management	B.S.	—	(27.8)	32.5	45.0	41.0	(45.6)	(57.0)	(52.0)	45.0	(50.0)	40.5
	M.S.	—	—	(36.0)	(49.5)	44.6	(51.2)	(57.0)	(51.5)	(56.0)	—	48.5
	Ph.D.	—	—	—	(46.7)	(61.5)	64.5	58.4	(65.5)	(73.2)	—	62.2
R&D management	B.S.	—	—	37.2	38.5	46.5	(50.0)	(41.5)	52.0	50.7	(51.5)	47.0
	M.S.	—	—	—	40.0	50.0	54.5	55.0	(60.5)	(61.5)	(55.0)	51.8
	Ph.D.	—	—	(43.0)	51.0	59.4	63.0	65.0	71.0	78.0	69.0	63.0
Basic research	B.S.	(22.7)	24.3	28.3	27.8	(41.2)	—	—	—	—	—	28.0
	M.S.	—	(27.1)	31.8	34.0	(40.2)	(35.8)	—	—	—	—	34.7
	Ph.D.	—	—	40.0	44.0	49.3	53.8	59.5	62.0	64.0	56.8	46.1
Applied research[b]	B.S.	22.5	24.6	29.6	34.2	37.2	41.0	43.0	46.0	48.0	(49.6)	32.0
	M.S.	—	(27.6)	31.0	36.0	39.0	39.6	47.0	46.1	51.5	(44.1)	37.0
	Ph.D.	—	—	39.5	42.0	46.6	51.0	55.0	53.8	52.8	60.0	46.2
Production[c]	B.S.	(20.2)	24.0	28.0	32.5	32.5	37.5	(39.5)	36.0	(40.0)	—	30.0
	M.S.	—	—	29.3	35.0	39.3	38.0	(37.0)	(41.5)	(48.5)	—	36.0
	Ph.D.	—	—	—	(45.0)	45.0	45.0	(47.0)	(54.2)	(52.0)	(52.8)	46.2
Marketing[d]	B.S.	—	(24.5)	29.2	40.4	48.0	(50.0)	(42.0)	(45.0)	50.8	(43.0)	42.0
	M.S.	—	—	32.0	37.2	(46.0)	(45.5)	—	(59.2)	(50.0)	—	45.0
	Ph.D.	—	—	—	(45.0)	(53.0)	55.6	(51.0)	(64.0)	—	—	53.0
Work specialty												
Analytical chemistry	B.S.	20.6	25.0	29.0	33.0	36.0	40.0	39.0	40.0	44.0	(40.0)	32.0
	M.S.	—	(26.4)	29.6	34.0	40.0	42.0	40.4	44.8	51.9	(41.2)	38.0
	Ph.D.	—	—	40.0	44.0	45.0	53.2	50.4	54.5	59.0	(65.0)	45.0
Agricultural and food chemistry	B.S.	—	—	(29.5)	(35.0)	(35.4)	—	—	—	—	—	39.0
	M.S.	—	—	(30.0)	(37.4)	(33.0)	(48.0)	—	—	—	—	36.8
	Ph.D.	—	—	(37.5)	43.5	50.2	53.0	(58.2)	(62.0)	—	—	50.3
Biochemistry and biotechnology	B.S.	—	(24.8)	(26.8)	(38.2)	—	—	—	—	—	—	28.0
	M.S.	—	—	(29.2)	34.8	(42.4)	—	—	—	—	—	35.5
	Ph.D.	—	—	38.9	43.0	50.0	48.4	54.8	(74.0)	(61.0)	—	47.1
Environmental chemistry	B.S.	—	22.5	33.0	38.2	(41.0)	(42.0)	(45.5)	(47.5)	—	(39.2)	35.0
	M.S.	—	—	(31.0)	37.2	(41.0)	(56.5)	—	—	—	—	38.0
	Ph.D.	—	—	—	(41.0)	(45.3)	(59.6)	(61.2)	(55.6)	(68.0)	—	52.9
Inorganic chemistry	B.S.	—	—	(31.0)	—	—	—	—	(59.5)	(42.2)	—	36.8
	M.S.	—	—	—	—	—	—	—	—	—	—	54.0
	Ph.D.	—	—	40.1	42.0	48.0	57.5	—	(56.0)	(64.0)	(51.2)	47.5
Medicinal and pharmaceutical chemistry	B.S.	—	24.0	27.4	(28.0)	(49.0)	—	—	(36.2)	(47.0)	—	31.4
	M.S.	—	—	(32.5)	(36.0)	40.5	(41.8)	—	(50.8)	—	—	37.5
	Ph.D.	—	—	40.0	43.0	48.8	57.7	55.9	54.2	66.0	70.7	50.0
Organic chemistry	B.S.	(22.8)	25.0	29.0	35.5	41.5	(45.6)	42.5	45.0	48.0	—	36.8
	M.S.	—	—	30.0	34.8	40.0	(39.0)	(46.0)	(55.0)	(55.4)	(55.0)	38.8
	Ph.D.	—	—	39.0	43.0	49.2	59.5	59.5	59.0	60.8	56.8	49.6
Physical chemistry	B.S.	—	(26.5)	(32.0)	—	—	—	—	—	—	—	38.0
	M.S.	—	—	(32.0)	(35.6)	—	—	—	—	—	—	35.6
	Ph.D.	—	—	(40.0)	(48.0)	51.2	57.0	70.0	61.3	76.0	(61.5)	55.0
Polymer chemistry	B.S.	(24.1)	24.0	32.0	36.0	41.0	47.0	(47.4)	49.5	50.0	(51.0)	36.6
	M.S.	—	—	35.0	39.8	44.0	50.8	50.0	52.3	(61.0)	—	42.6
	Ph.D.	—	—	39.4	44.1	49.9	56.1	59.3	62.3	62.5	55.8	51.8

a As of March 1, 1986. b Includes development. c Includes quality control. d Includes purchasing, technical service, and economic evaluation. **Note:** Where no salary data are shown, sample is too small to provide a meaningful figure; data in parentheses are from relatively small samples, as well, and should be viewed with caution. **Source:** ACS survey

Unemployment edges up a bit this year for chemists

Employment status[a]	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976
Employed full time	94.8%	95.2%	93.7%	93.5%	94.9%	95.6%	95.9%	95.0%	95.7%	95.4%	94.7%
Employed part time	1.5	1.5	1.7	1.7	1.4	1.1	1.0	2.0	1.0	1.1	1.3
Postdoctoral or fellowship	2.0	1.9	2.9	2.6	2.2	2.2	2.2	1.9	1.9	2.1	2.2
Unemployed	1.7	1.4	1.7	2.2	1.5	1.1	0.9	1.1	1.4	1.5	1.9

a As of March 1, 1986; excludes chemists who are not employed but not seeking employment. Source: ACS survey

Pay is highest for industrial chemists working for oil firms

Industry	% of industrial chemists				Mean salary ($ thousands)[a]		
	All chemists	B.S.	M.S.	Ph.D.	B.S.	M.S.	Ph.D.
Pharmaceuticals[b]	18%	17%	19%	18%	$35.9	$38.7	$52.2
Chemicals[c]	16	13	15	19	36.9	40.2	50.2
Agricultural chemicals	7	5	6	9	36.5	40.8	50.0
Petroleum and natural gas	6	5	5	8	42.3	46.7	56.7
Coatings	6	8	6	4	35.8	42.6	51.6
Electronics	5	6	5	5	35.3	40.5	52.8
Biochemicals and biotechnology	4	3	3	5	40.5	33.0	47.5
Food	4	5	5	3	37.5	36.6	43.5
Metals and minerals	3	4	3	2	33.7	40.8	43.9
Soaps and detergents	3	3	3	2	37.2	59.7	48.7
Rubber	2	3	3	2	34.6	41.1	48.6
Paper	2	2	1	2	38.2	42.2	52.1
Other manufacturing	17	17	17	16	37.1	40.7	50.6
Nonmanufacturing	7	10	9	5	34.1	40.9	50.7

a As of March 1, 1986; to facilitate comparison, mean salaries are adjusted for differences in the average experience for each group. b Includes personal care products. c Excludes chemical sectors listed separately. Source: ACS survey

Joblessness is greatest among industrial chemists

	% of chemists in category	% unemployed[a]
MOST RECENT EMPLOYER		
Industry	62%	2.2%
Academic	22	0.8
Government	10	0.3
Other	6	1.7
MOST RECENT WORK FUNCTION		
R&D	44%	1.5%
R&D management	12	1.7
Teaching	11	0.9
General management	8	2.2
Production[b]	7	3.5
Marketing[c]	5	3.5
Other	12	1.6
MOST RECENT WORK SPECIALTY		
Analytical	20%	1.6%
Organic	14	1.7
Polymer	12	1.9
Biochemistry[d]	9	1.4
Physical[e]	8	1.6
Medicinal[f]	7	1.8
Environmental	6	1.8
Inorganic	5	2.2
Agricultural[g]	3	0.3
Other	9	1.9
Nonchemistry	7	1.9

a As of March 1, 1986; excludes chemists who are not employed but not seeking employment. b Includes quality control. c Includes purchasing, technical service, and economic evaluation. d Includes biotechnology. e Includes theoretical chemistry. f Includes pharmaceutical and clinical chemistry. g Includes food chemistry. Source: ACS survey

experience on salary levels is greatest during the first 20 years or so after entering the profession. Thus, the median salary of a B.S. chemist with a nonacademic job who graduated 20 to 24 years ago is double that of the individual who has graduated in just the past year. But the median rises only another 10% for those with an additional 15 years of experience.

Sex and experience are not the only determinants of salary, to be sure. Where a chemist works is another factor. Salaries tend to be highest for those employed in industry, lowest for those who teach. For academicians, moreover, chemists are likely to earn more if they teach at a Ph.D.-granting school.

Among industrial chemists, the median salary has long been highest for those working for petroleum companies, whereas the lowest medians are in industries that employ relatively few chemists, such as metals, rubber, and food. And for industrial chemists, too, as would be expected, managerial positions are the most remunerative, although basic research and marketing also seem to pay well if allowance is made for length of experience.

In any event, most chemists seem satisfied with how they earn their living. Asked if they had it to do over again, would they take the same job that they now have, 77% of the respondents to the ACS survey agree that they would; only 15% would not (8% have no opinion). Satisfaction apparently is strongest among chemists working at universities and colleges; 81% would take the same job, only 13% would not.

A similar finding is that 16% of the survey respondents who are now employed full-time claim to be actively seeking a new job.

The data reported here on employment and salaries for the chemical profession are based on nearly 11,000 responses to a mail survey of a random sample of ACS members that was made by the ACS Office of Statistical Services last March. The survey was limited to members who reside in the U.S., are under age 70, and are neither emeritus nor student members.

A full report on results of the annual ACS survey for 1986, containing more detail, will be published in July by the Office of Statistical Services. The report, "Salaries 1986," can be purchased from Distribution, Room 210, American Chemical Society, 1155—16th St., N.W., Washington, D.C. 20036. The price of this year's report is $99 per copy. □